Attachment: Delivery Documentation for the Updated Landsat-7 Star Catalogs

This memorandum documents the analysis and recommendations of quality assurance completed on the recently regenerated Landsat-7 Run and Supplemental star catalogs. In addition, the memorandum provides mission specific information such as the Supplemental Catalog format and detailed descriptions of the Run Catalog quality flags.

INTRODUCTION

Recently the SKYMAP SKY2000 Master Catalog (MC) used to generate mission-specific Run Catalogs was revised and improved to produce Version 4 of the SKY2000 MC. This version of the MC includes complete replacement from current sources of all variable star identifiers and variability data. With the exceptions of the position, position uncertainty, and proper motion fields as described below, the Supplemental Catalog is a data word subset of the Master Catalog containing the same stars as the Landsat-7 Run Catalog, but with additional information requested by Landsat-7 mission personnel included.

Two sets of Run and Supplemental catalogs are being delivered at the present time; one set for use on the ground containing 13424 stars in each catalog, and a second set for use onboard the spacecraft containing 700 stars in each catalog. The 700-star catalogs are proper subsets of the 13424-star catalogs, and represent an updated group of stars for onboard use selected by Landsat-7 flight operations personnel based on flight data.

MISSION REQUIREMENTS

The limiting sensor passband magnitude of both 13424-star catalogs is 6.2. The angular radius within which MMSCAT was to combine entries and calculate blended magnitudes was set to 0.1 arcseconds, which effectively means that no blending was performed. Thus, all stars with distinct entries in the Master Catalog found to have individual sensor passband magnitudes of 6.2 or brighter are included in the 13424-star Run and Supplemental catalogs, regardless of their angular separations from one another. Accordingly, no adjustments have been made to positional uncertainties to reflect the presence of interfering near-neighbor stars. Positions and position uncertainties in all the catalogs delivered have been propagated to epoch January 1, 2003 (J2003).

PROPAGATION OF RUN AND SUPPLEMENTAL CATALOG ASTROMETRIC DATA

The position and position uncertainty information in all of the delivered catalogs is in the Julian-based system at epoch January 1, 2003. In order to rigorously propagate the positions and position uncertainties, an input file of the 13424 catalog stars was created containing a SKY2000 Version 4 data record plus a data record from the astrometric catalog from which the SKY2000 position and proper motion data were drawn. The additional information available in this input file allowed the rigorous propagation of positions and position uncertainties to the chosen epoch. The position propagation

included the application of proper motion, followed by the application of precession and nutation to all catalog positions. The propagation of the position uncertainties utilized the position uncertainties at the original epochs of the positions together with the proper motion uncertainties to allow the propagation of all catalog position uncertainties.

CATALOGS PRODUCED

The catalogs prepared for delivery are two Run Catalogs and two Landsat-7-specific Supplemental Catalogs. The Supplemental Catalog contains positions, position uncertainties, proper motions, radial velocities, parallaxes, parallax uncertainties, magnitude, passband, and system data for MC passbands 1-3, and variability data. The format of the Run Catalog is unchanged from past deliveries, and the format of the Supplemental Catalog is the same as in the June, 2000, Landsat-7 catalog delivery, where a number of data fields were added to each record. The detailed description of the Supplemental Catalog format follows:

- Field 1 (bytes 1-8) SKYMAP number for this star.
- Field 2 (10-19) right ascension of the star in hours, minutes, and seconds of time (epoch and equinox J2003).
- Field 3 (21-30) declination of the star in degrees, minutes, and seconds of arc (epoch and equinox J2003, sign in byte 21).
- Field 4 (32-37) RMS position uncertainty for the star at epoch 01/01/2003, in arcseconds.
- Field 5 (39-47) proper motion of the star in right ascension, in arcseconds/year (without the cosine delta multiplier, sign in byte 39).
- Field 6 (49-57) proper motion of the star in declination, in arcseconds/year (sign in byte 49).
- Field 7 (59-65) radial velocity of the star, in kilometers/second (sign in byte 59).
- Field 8 (67-72) trigonometric parallax of the star, in arcseconds (sign in byte 67).
- Field 9 (74-79) trigonometric parallax uncertainty of the star, in arcseconds.
- Field 10 (81-86) passband #1 magnitude, in magnitudes.
- Field 11 (88-92) passband #1 magnitude uncertainty, in magnitudes.
- Field 12 (94) passband #1 photometric system (see Reference 2 for definitions).
- Field 13 (96) passband #1 passband (see Reference 2 for definitions).
- Field 14 (98-103) passband #2 magnitude, in magnitudes.
- Field 15 (105-109) passband #2 magnitude uncertainty, in magnitudes.
- Field 16 (111) passband #2 photometric system (see Reference 2 for definitions).

- Field 17 (113) passband #2 passband (see Reference 2 for definitions).
- Field 18 (115-120) passband #3 magnitude, in magnitudes.
- Field 19 (122-126) passband #3 magnitude uncertainty, in magnitudes.
- Field 20 (128) passband #3 photometric system (see Reference 2 for definitions).
- Field 21 (130) passband #3 passband (see Reference 2 for definitions).
- Field 22 (132-141) variable star name or number, free-format text.
- Field 23 (143-147) variability amplitude, in magnitudes.
- Field 24 (149) passband of variability (see Reference 2 for definitions).

The catalogs will be delivered electronically via e-mail. They will also be stored in the SKYMAP area of the FDD NIS.

RUN CATALOG QUALITY FLAG DEFINITIONS

Each Run Catalog entry (see Table A-1 for the format of a Run Catalog entry) contains eight hexadecimal quality flags used to assist in determining the suitability of a given star as a potential guide star for attitude determination. Individual quality flags and the bin values selected during the generation of the Landsat-7 Run Catalog are described in this section.

The first quality flag is the variability flag. It maps a star's variability amplitude in magnitudes as described in Table A-2. In general, this variability amplitude is not the amplitude of variability in the sensor passband of a particular CCDST. Rather, it is the observed variability in a particular astronomical passband (e.g., Johnson *V*). However, this amplitude can be used to obtain a rough idea of the degree of variability of a particular star. Note that this quality flag has *not* been updated to reflect the improvements to the variability data found in the SKY2000 Version 4 MC. This would have required a complete regeneration of the Run Catalogs, which was deemed too time-consuming for the present update effort. The variability data fields in the Supplemental catalogs have been updated, as this was deemed more useful to mission personnel utilizing the catalogs.

Table A-1. Run Catalog Record Format

<table>
<tr><th>Name</th><th>Type</th><th>Description</th></tr>
<tr><td>ISTDAT</td><td>I*4</td><td>SKYMAP number</td></tr>
<tr><td>FSTDAT(1)</td><td>R*4</td><td>X-component of GCI unit vector</td></tr>
<tr><td>FSTDAT(2)</td><td>R*4</td><td>Y-component of GCI unit vector</td></tr>
<tr><td>FSTDAT(3)</td><td>R*4</td><td>Z-component of GCI unit vector</td></tr>
<tr><td>FSTDAT(4)</td><td>R*4</td><td>Visual (V) or instrumental magnitude</td></tr>
<tr><td>FSTDAT(5)</td><td>R*4</td><td>Composite word (proper motion word):

Integer part—Direction of star’s total proper motion vector divided by 360.0, multiplied by 1000, and rounded to the nearest integer

Fractional part—Magnitude of star’s proper motion vector in arcseconds per year divided by 100</td></tr>
<tr><td>FSTDAT(6)</td><td>R*4</td><td>Composite word (quality flag word): Contains eight 4-bit flags used to quantify the quality of a star as a potential guide star; each flag measures the quality of a different physical aspect and includes the following:

<table>
<tr><th>Bits</th><th>Description</th></tr>
<tr><td>1-4</td><td>Variability</td></tr>
<tr><td>5-8</td><td>Color</td></tr>
<tr><td>9-12</td><td>Multiplicity</td></tr>
<tr><td>13-16</td><td>Near-neighbors</td></tr>
<tr><td>17-20</td><td>Position knowledge error</td></tr>
<tr><td>21-24</td><td>Magnitude knowledge error</td></tr>
<tr><td>25-28</td><td>Trackability near-neighbor (spare)</td></tr>
<tr><td>29-32</td><td>Identifiability near-neighbor (spare)</td></tr>
</table>
</td></tr>
<tr><td>FSTDAT(7)</td><td>R*4</td><td>Composite word (color word):

Integer part—(B-V) color multiplied by 100 and rounded to the nearest integer; = 999 if no (B-V) color is available

Fractional part—SKYMAP-coded spectral type divided by 100000</td></tr>
</table>

Table A-2. Run Catalog Quality Flag 1 Definition (Variability)

Flag Value	Definition
0	0.0 = amplitude < 0.1
1	0.1 = amplitude < 0.2
2	0.2 = amplitude < 0.3
3	0.3 = amplitude < 0.4
4	0.4 = amplitude < 0.5
5	0.5 = amplitude < 0.75
6	0.75 = amplitude < 1.0
7	1.0 = amplitude < 2.0
8	2.0 = amplitude < 3.0
9	3.0 = amplitude < 4.0
10	4.0 = amplitude < 5.0
11	5.0 = amplitude < 6.0
12	6.0 = amplitude < 8.0
13	8.0 = amplitude < 10.0
14	Amplitude = 10.0
15	Known variable with unknown amplitude

The second quality flag is the color flag. It maps the difference between the input magnitude on a standard astronomical passband (e.g., Johnson *V*) used to predict the sensor passband magnitude by MMSCAT, and the predicted sensor passband magnitude itself. This difference (in magnitudes) indicates the degree of difference between the input magnitude and the output magnitude prediction. Table A-3 describes the mapping used to assign values to this flag.

Table A-3. Run Catalog Quality Flag 2 Definition (Color)

Flag Value	Definition
0	-100.0 = color < 0.05
1	0.05 = color < 0.1
2	0.1 = color < 0.2
3	0.2 = color < 0.3
4	0.3 = color < 0.4
5	0.4 = color < 0.5
6	0.5 = color < 0.6
7	0.6 = color < 0.85
8	0.85 = color < 1.0
9	1.0 = color < 1.25
10	1.25 = color < 1.5
11	1.5 = color < 1.75
12	1.75 = color < 2.0
13	2.0 = color < 2.5
14	2.5 = color < 3.0
15	Color = 3.0

The third quality flag is the multiplicity flag. For stars that are known to be members of double- or multiple-star systems, it maps the magnitude difference (in magnitudes) between the two brightest components. See Table A-4 for a detailed description of the mapping of this quality flag.

The fourth flag is the near-neighbor flag. It maps net position uncertainties of primary stars as a result of interfering near-neighbor stars. Since no magnitude blending of close pairs was performed in the Landsat-7 catalogs, it is assumed that star positions are not degraded by the presence of detectable bright near-neighbors. Hence, *quality flag four does not contain any useful information in the case of the Landsat-7 Run Catalog.*

Table A-4. Run Catalog Quality Flag 3 Definition (Multiplicity)

Flag Value	Definition
0	Not a multiple star or multiple star treated as a near-neighbor
1	Nearest star is either greater than or equal to 6.0 magnitudes fainter, or is less than 0.1 arcseconds away, or if definition of values 0 or 2-7 does not apply
2	4.0 = magnitude difference < 6.0
3	3.0 = magnitude difference < 4.0
4	2.0 = magnitude difference < 3.0
5	1.0 = magnitude difference < 2.0
6	0.5 = magnitude difference < 1.0
7	Magnitude difference < 0.5

The fifth flag is the position knowledge uncertainty flag. It maps the RMS position uncertainty at the epoch of the Run Catalog (J2003, in arcseconds). The mapping used to assign values to this flag is described in Table A-5.

Table A-5. Run Catalog Quality Flag 5 Definition (Position Knowledge)

Flag Value	Definition
0	0.0 = position measurement uncertainty < 0.01
1	0.01 = position measurement uncertainty < 0.02
2	0.02 = position measurement uncertainty < 0.03
3	0.03 = position measurement uncertainty < 0.04
4	0.04 = position measurement uncertainty < 0.05
5	0.05 = position measurement uncertainty < 0.075
6	0.075 = position measurement uncertainty < 0.1
7	0.1 = position measurement uncertainty < 0.2
8	0.2 = position measurement uncertainty < 0.4
9	0.4 = position measurement uncertainty < 0.8
10	0.8 = position measurement uncertainty < 1.2
11	1.2 = position measurement uncertainty < 1.6
12	1.6 = position measurement uncertainty < 2.0
13	2.0 = position measurement uncertainty < 3.0
14	3.0 = position measurement uncertainty < 9999.0
15	Position measurement uncertainty = 9999.0

The sixth flag is the predicted magnitude knowledge uncertainty flag. It maps the uncertainties associated with predicted sensor passband magnitudes from MMSCAT. This uncertainty includes the initial uncertainty of the input magnitude used by MMSCAT and an estimate of the uncertainties associated with different methods of predicting sensor passband magnitudes used by MMSCAT. Table A-6 details the mapping used to assign values to this flag.

Table A-6. Run Catalog Quality Flag 6 Definition (Predicted Magnitude)

Flag Value	Definition
0	0.0 = magnitude error < 0.05
1	0.05 = magnitude error < 0.1
2	0.1 = magnitude error < 0.2
3	0.2 = magnitude error < 0.3
4	0.3 = magnitude error < 0.4
5	0.4 = magnitude error < 0.5
6	0.5 = magnitude error < 0.6
7	0.6 = magnitude error < 0.8
8	0.8 = magnitude error < 1.0
9	1.0 = magnitude error < 1.25
10	1.25 = magnitude error < 1.5
11	1.5 = magnitude error < 1.75
12	1.75 = magnitude error < 2.0
13	2.0 = magnitude error < 2.25
14	2.25 = magnitude error < 2.5
15	Magnitude error = 2.5

The seventh quality flag is the trackability near-neighbor flag. It maps the angle in degrees to the nearest star either brighter than or up to 4.0 magnitudes fainter than the Run Catalog star. Nearby stars can interfere with the ability of a star sensor to track a particular star, and this flag serves to indicate the presence of potentially interfering nearby stars. Table A-7 details the mapping used to assign values to this flag.

Table A-7. Run Catalog Quality Flag 7 Definition (Trackability)

Flag Value	Definition
0	Near-neighbor separation = 1.0
1	0.8 = near-neighbor separation < 1.0
2	0.6 = near-neighbor separation < 0.8
3	0.4 = near-neighbor separation < 0.6
4	0.3 = near-neighbor separation < 0.4
5	0.2 = near-neighbor separation < 0.3
6	0.1 = near-neighbor separation < 0.2
7	0.08 = near-neighbor separation < 0.1
8	0.06 = near-neighbor separation < 0.08
9	0.04 = near-neighbor separation < 0.06
10	0.03 = near-neighbor separation < 0.04
11	0.02 = near-neighbor separation < 0.03
12	0.01 = near-neighbor separation < 0.02
13	0.005 = near-neighbor separation < 0.01
14	0.0025 = near-neighbor separation < 0.005
15	0.0 = near-neighbor separation < 0.0025

The eighth flag is the identifiability near-neighbor flag. It maps the angle in degrees to the nearest star within 1.0 magnitude of the Run Catalog star in brightness. A nearby star similar in brightness to a particular Run Catalog star can be confused with the Run Catalog star and tracked instead of the intended star. This quality flag serves to help identify potential situations of this sort. Table A-8 details the mapping used to assign values to this flag.

Table A-8. Run Catalog Quality Flag 8 Definition (Identifiability)

Flag Value	Definition
0	Near-neighbor separation = 5.0
1	4.0 = near-neighbor separation < 5.0
2	3.0 = near-neighbor separation < 4.0
3	2.0 = near-neighbor separation < 3.0
4	1.0 = near-neighbor separation < 2.0
5	0.5 = near-neighbor separation < 1.0
6	0.25 = near-neighbor separation < 0.5
7	0.1 = near-neighbor separation < 0.25
8	0.05 = near-neighbor separation < 0.1
9	0.025 = near-neighbor separation < 0.05
10	0.02 = near-neighbor separation < 0.025
11	0.015 = near-neighbor separation < 0.02
12	0.01 = near-neighbor separation < 0.015
13	0.005 = near-neighbor separation < 0.01
14	0.0025 = near-neighbor separation < 0.005
15	0.0 = near-neighbor separation < 0.0025

RECOMMENDATIONS FOR CATALOG USE

The 13424-star Run and Supplemental catalogs delivered are all-sky catalogs (see Figure A-1). Declination cutoffs have been implicitly applied to the 700-star catalogs in creating the subset of entries selected by mission personnel (see Figure A-2).

Figure A-1. Landsat-7 13424-Star Catalog Positions

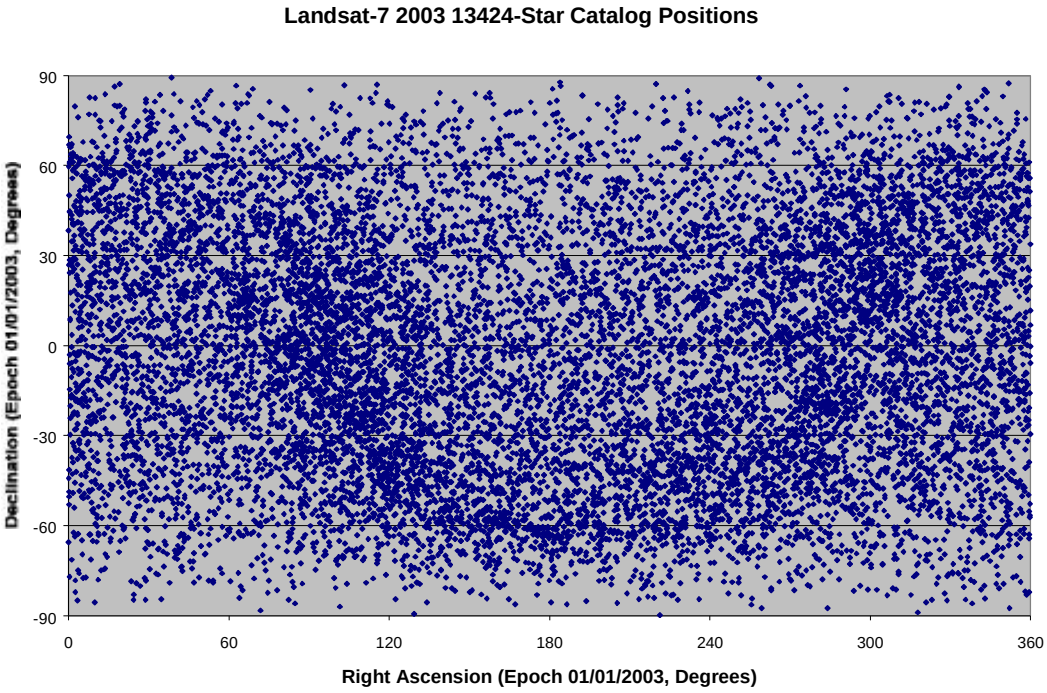
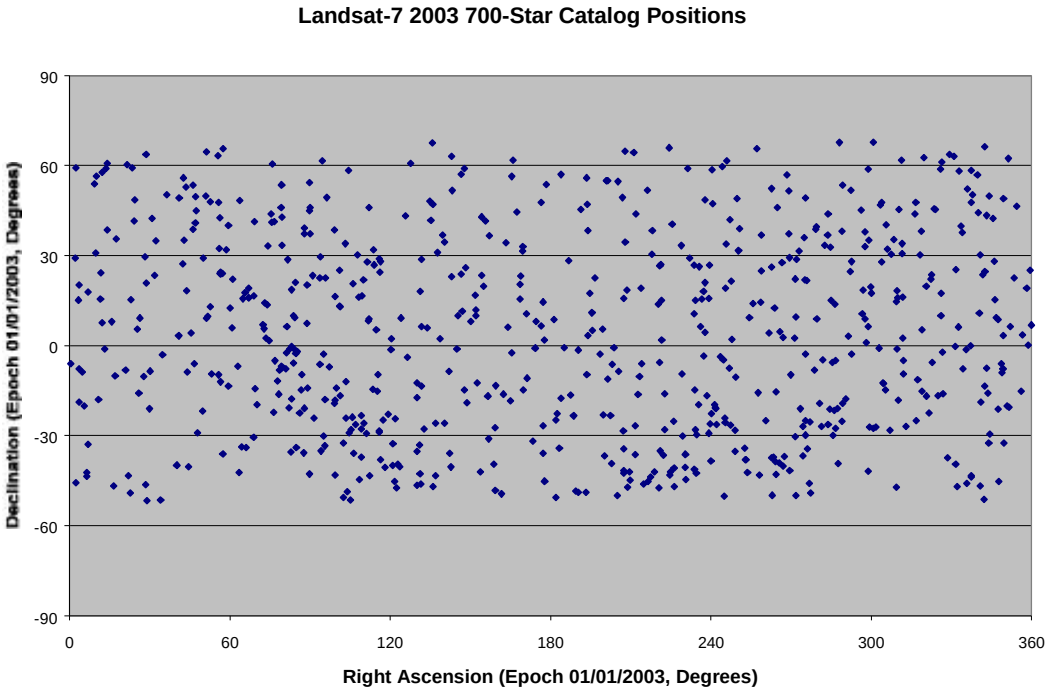


Figure A-2. Landsat-7 700-Star Catalog Positions



The effects of including all stars brighter than the cutoff magnitude of 6.2 (in the sensor passband) regardless of proximity to other bright stars are not clear in the case of the Landsat-7 Celestial Sensor Assembly, which is a slit sensor. Typically, MMSCAT is run with a blending radius within which it will combine two or more stars into a single entry with a blended sensor passband magnitude. The formula used is the classic astronomical magnitude blending formula:

$$m_{blend} = m_{primary} - 2.5*\log(1+2.5119^{-?m}),$$

where $?m = m_{secondary} - m_{primary}$, with the secondary always taken as being the fainter star. Positions can be combined in a similar manner, with weights being assigned according to the fluxes generated by each star, but MMSCAT does not have this capability. In any case, neither the sensor passband magnitudes nor the positions are blended in the Landsat-7 catalogs unless the corresponding values used from the MC were themselves blended (as will occur for pairs or multiples with separations less than approximately one arcsecond).

Variable stars are included in the Landsat-7 catalogs and can be identified by using quality flag 1 (variability amplitude, see Table A-2) in the Run Catalog and by using the last three fields (variable star identifier and variability amplitude data) in the Supplemental Catalog. These stars are not recommended for use as guide stars due to the element of uncertainty involved when attempting to acquire and track them.

REFERENCES

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4. Sande, C. *SKYMAP Requirements, Functional, and Mathematical Specifications (Volume 1, Revision 4): SKYMAP System User's Guide*, CSC-96-932-25, August 1999.

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